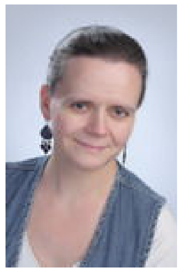
Ágnes Gulyás

Evaluating climate-related ecosystem services of urban tree stands in Szeged (Hungary)

Márton Kiss[1], Ágnes Takács[1], Ágnes Gulyás[1]
[1] *Department of Climatology and Landscape Ecology,University of Szeged*
P.O. Box 653., H-6701 Szeged, Hungary
kiss.marton@geo.u-szeged.hu

1. Introduction

The rapid growth of urban population and the global climate change call for the elaboration and evaluation of different adaptation and mitigation strategies in the antropogenically modified climatic circumstances. Among these strategies, one of the most important is the planting and maintenance of trees and other green spaces. On one hand, vegetation is directly effective through shading and evapotranspiration, improving life quality of the settlements' population by decreasing heat stress. In addition, urban tree stands modify the city's climatic characteristics and air quality also by the sequestration of carbon dioxide and the removal of various air pollutants, and by reducing stormwater runoff (Jim and Chen, 2008; Kirnbauer et al., 2013; Nowak et al., 2013). Furthermore, vegetation, particularly trees, are considered to have significant aesthetic and eco-psychological values (O'Campo et al., 2009; Tyrväinen et al., 2003).

The above-mentioned characteristics of trees and green spaces can be considered as regulating ecosystem services. The multifunctionality of urban ecosystems is a well-known fact (Haase et al., 2014), the methodology of the evaluation of ecosystem sevices could play an important role in its promotion and its incorporation in decision-making processes. The essence of this approach, originating primarily from the fields of landscape ecology and ecological economics, is to quantify those goods and services of ecosystem and landscape elements that contribute directly or indirectly to human well-being (Bolund and Hunhammar, 1999; Gómez-Baggethun and Barton, 2013). Due to the integrated approach and monetary quantification (which can be carried out for some of the services), this methodology could play an important role in furthering the interests of nature conservation. This is indicated by several significant international policy documents, and the foundation of IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services) (MEA, 2005; Perrings et al., 2011; TEEB, 2010a,b).

The evaluations of climate- and air quality-related ecosystem services can be carried out relatively easily using allometric and growth equations of different tree species (based on data from forestry practice). Based on that, several targeted models have been developed using these data to calculate some of these services, mainly carbon sequestration and air pollution removal, completed sometimes with monetary evaluations (i-Tree, 2014; Liu et al., 2008). These have been used in many cities in the world, and sometimes they are integral part of the official urban tree management processes (City of Melbourne, 2012; Rogers et al., 2011). Yet we are not aware of studies published on assessments of climate- and air quality-related ecosystem services, based on large tree inventories from Central Eastern Europe.

Following these research needs, we provide and discuss the results of an individual based ecosystem service assessment, based on a complete tree inventory. The analyses are referring to tree stands in the centre of Szeged (Hungary). Our first goal was to investigate the significance of the urban trees from the point of view of two services, carbon sequestration and air pollution removal, among Central European climatic circumstances. This was achieved with the adaptation of a targeted model (i-Tree Eco). Another goal was to assess the service providing capacity of different species, with relation to their general condition. This also needed the complete inventory, where data representing stands of different species were available for comparison.

2. Data and methods

2.1 Study area

The study area of the analysis was in the centre of Szeged, situated in South-East Hungary. The city is characterized with a dry-warm continental climate. Szeged is the administrative centre of Csongrád county, with ca. 170000 inhabitants. Because of its size, the urban heat island effect and the air pollution are considerable, which were studied in detail in previous years (Makra, 2005; Unger et al., 2014). The downtown area was the main area of our investigations where the urban stands are located. The whole investigated stand (total urban forest) is composed of 2846 trees, situated mainly in tree lines, while the rest are park stands on squares.

2.2 Data and materials

The analyses are based on a field-based complete tree inventory, that had been produced in the vegetation period of 2012 and 2013, in strong cooperation with the municipal public utility company responsible for green space management. The exact locations of the trees were available from a baseline GIS database of the city, which helped to carry out the field survey. For that, we applied the protocol of the i-Tree model (i-Tree, 2014). We recorded the attributes of every street and park trees in the study area, if its diameter at breast height (DBH) exceeded 5 cm. The height of the tree, the height to base of live crown and the crown diameter were measured using Vertex III ultrasonic hypsometer. The diameter was recorded at 1,37 meter (breast height), under which, in case of multi-stemmed individuals, every stem was measured which exceeded 5 cm in DBH. The ratio of canopy missing and ratio of branch dieback in crown data are used to rate tree condition and to adjust downward leaf area and biomass data, which are calculated with the help of allometric equations (Nowak et al., 2008). Percent of canopy missing and dieback data were recorded in 5-percent intervals in the field. The growth of a certain individual is corrected with the crown light exposure (CLE) data (number of sides of the tree receiving sunlight – maximum of five). The data collected in the field was primarily imported and stored in „Greenformatic" software, which was developed in Hungary specifically for urban tree registers, and which is capable of storing i-Tree datasets. From Greenformatic, we exported the data into MS Access format, which is the required format of the applied model.

2.3 The i-Tree Eco model

The elements of i-Tree software suite are worldwide used tools for calculating climate- and air quality-related ecosystem services of urban trees. From the tools of i-Tree (formerly UFORE – Urban Forest Effects Model) suite (i-Tree Eco, Streets, Hydro, Design), Eco is the most suitable for international use. The model calculations are based on the well-defined allometric relationships between indicators of the relevant ecosystem services (amount of biomass, leaf area) and measured size parameters of the trees. The first part of the model results cover the most important structural characteristics of the urban forest (leaf area, canopy cover, tree condition, etc.). The tree condition categories are given based on the proportion of branch dieback in crown data (excellent: <1%, good: 1-10%, fair: 11-25%, poor: 26-50%, critical: 51-75%, dying: 76-99%). The second main part of the results include the estimates on the investigated ecosystem services. Carbon storage is quantified with the help of the above-mentioned allometric equations. Annual growth (from which annual carbon seuestration is calculated) estimates are based primarily on standardized growth rates (that take into account climatic characteristics of the study area), which are adjusted based on tree condition and crown light exposure data (which represent forest or open-grown conditions). The air pollution removal (dry deposition) calculations are carried out using pollutant concentration datasets of the study area, by calculating deposition velocities, for which detailed meteorological datasets are needed from the study site.

The i-Tree model have to be adapted to use outside the U.S. It needs the integration of some basic geographical data, information on the growth characteristics of the tree species specific of the study area, local meteorological and air pollutant datasets. As all of the species in our inventory can be found in the i-Tree Eco species database (partly because of their American origin), no additional species information was needed. The general climatic characteristics of the area (e.g. number of frost-free days) affect the annual growth rates, while the meteorological data with high temporal resolution is needed for the calculation of deposition velocities of pollutants. The meteorological datasets are from the meteorological station of Szeged (run by the Hungarian Meteorological Service). Air pollution removal was calculated for CO, NO_2, PM10, SO_2 and O_3, their hourly concentration datasets were provided by the local station of the Hungarian National Air Quality Network. After compiling and proper formatting the above-mentioned datasets (together with the tree inventory), the data processing was carried out by the US Forest Service. The model was implemented for the year 2012 (this year's meteorological and air pollution datasets were used).

3. Results

3.1 Structural characteristics of the urban forest

The total urban forest of the city is characterized with high species diversity, exactly 100 species can be found in this area of a bit more than 2 km^2. A bit less than half of them (48) are native in Hungary. The majority of the urban forest consists of street tree alleys, however the tree populations in parks are also planted stands. The ten most common species amount to 70% of the whole urban forest (1992 individuals, Tab. 1).

	Number of trees	Share in the total population (%)	Leaf Area (m^2)	Share in the total leaf area (%)	Average DBH (cm)
Platanus hybrida	305	10,7	229455,5	37,7	63,0
Tilia cordata	295	10,4	36249,4	5.9	28,4
Sophora japonica	276	9,7	55252,7	9,1	47,5
Celtis occidentalis	252	8,9	61215,2	10,1	36,2
Tilia tomentosa	235	8,3	19355,9	3,2	18,0
Koelreuteria pan.	184	6,5	21567,1	3,5	29,4
Tilia platyphyllos	165	5,8	27978,8	4,6	28,2
Ginkgo biloba	111	3,9	14737,5	2,4	33,2
Acer platanoides	87	3,1	13547,9	2,2	20,3
Fraxinus ornus	82	2,9	9807,0	1,6	22,1

Tab. 1. Characteristics of the ten most abundant species in the studied urban forest of Szeged.

For most species, there is a dominant size range (which can be described with the standard deviation of DBH). This shows that in the last years, different species were preferred when planting tree lines. More than half of the species (53) have less than 10 individuals, these were planted partly when diverse parks were created or if individuals of formerly homogenous tree alleys were substituted with new species.

Leaf area is one of the most important state indicators of the investigated ecosystem services, therefore examining the weight of different species within the total population is necessary (Fig. 1). The Platanus hybrida stand is outsanding in leaf area, as it is the main species in the tree alleys with the oldest and biggest individuals of the city. The population of Tilia tomentosa has very small amount of leaf area, compared to its share in the number of individuals, it refers to that most of these trees form a recently planted homogenous tree line.

The health condition of the populations of different species might be a factor that affects the amount of leaf area heavily. It can be said that the total studied stand is in a considerably good condition, most of the individuals were classified into „excellent" or „good" categories. This is partly a consequence of the design of the model: health condition categories are defined by the crown dieback rates, and trees are categorized into worse (fair or worse) categories if the dieback value is above 10%. But proper management also plays a significant role (trees in very bad health status are replaced relatively quickly). But big differences between species can also be observed from the point of view of tree condition, which highly influence the amount of the provided services. For example, the populations of e.g. Platanus hybrida and Acer platanoides are in a good general condition (only 14,7% and 19,5% of their individuals are in worse tree condition. The same is for Tilia tomentosa and Fraxinus ornus stands (60,9% of the inidividuals are in excellent condition in both populations). In contrast, considerable parts of the populations of two native Tilia species (T. cordata, T. platyphyllos) are ranked into worse health categories (27,4% and 24,8%), similar observations can be made at the individuals of the Sophora japonica population (19% and 31,2%).

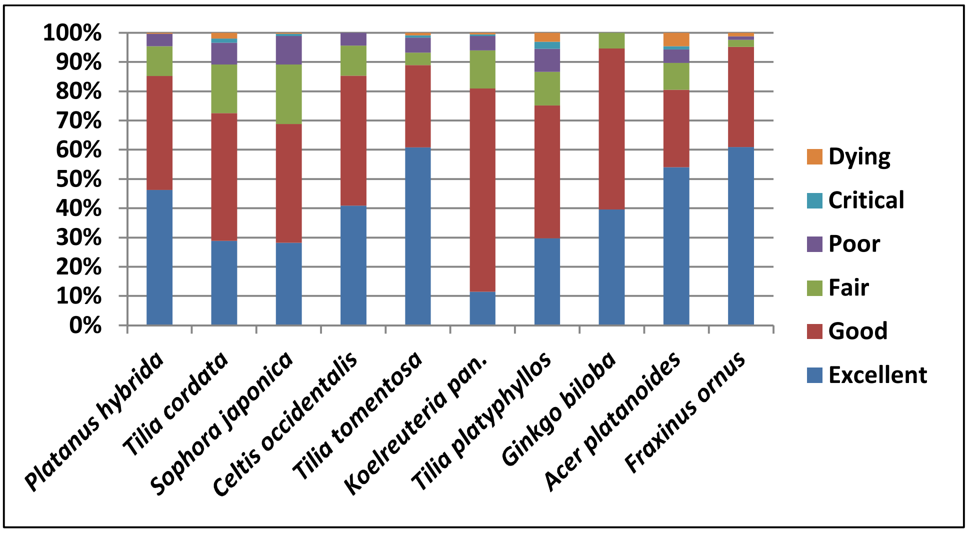

Fig. 1. Tree condition in the populations of the ten most common species.

3.2 Carbon storage and sequestration

Differences between species in carbon sequestration and storage capacity are mainly determined by the differences in size distribution (Tab. 2). The Platanus hybrida population can be characterized with extremely high annual sequestration, which can reach 60 kg/year or even more for the greatest individuals. The 305 Platanus hybrida trees store 428,9 tons of carbon, which is more than one third of the total stored carbon (1169 t) of the studied urban forest. The order of the species based on carbon storage, is obviously mostly parallel with the one based on the leaf area (both have strong connection with primary production). However, in some cases, slight differences can be detected, that may indicate the health status of the species. For instance, the Sophora japonica population clearly has a relatively small leaf area (9,1% share from the leaf area of the total urban forest) compared to its carbon storage capacity (16,9%). This is a consequence of the high values of crown missing (owing mainly to management interventions), which do not affect the high amounts of stored carbon in the stems of the trees. The relatively good leaf area/stored carbon ratio refers to undisturbed crowns, but besides that, the dieback rates could be high, which could be a sign of the weak tolerance of urban circumstances. E.g. in the case of Tilia platyphyllos (share in the total leaf area: 4,6%, share in carbon storage: 2,1%), the average value of crown dieback is 12,6%, compared to the value of the total population (8,4%).

	Carbon sequestration per tree (kg/yr)	**Carbon storage (kg)**	**Air pollution removal (kg/yr)**
Platanus hybrida	35,9	428904,7	1059,1
Tilia cordata	7,5	50013,3	238,3
Sophora japonica	23,5	197693,5	556,8
Celtis occidentalis	15,8	102569,7	379,7
Tilia tomentosa	4,4	17631,3	118,3
Koelreuteria paniculata	11,9	37531,0	252,9
Tilia platyphyllos	7,3	24468,3	285,3
Ginkgo biloba	14,4	37444,1	197,3
Acer platanoides	6,8	11790,4	243,9
Fraxinus ornus	6,8	8737,8	233,4

Tab. 2.Comparison of the ten most common species from the two investigated ecosystem services.

3.2 Air pollution removal

The differences in air pollution removal between species and its relation to the average diameter at breast height are basically parallel with the previously described leaf area-carbon storage relations, as leaf area is the ecosystem indicator during the quantification of the service. The average removal per tree (calculated by summarizing the values of all of the pollutants) is ranging between 200-400 g/yr for most species, this is outweighed only by Platanus hybrida and Sophora japonica individuals.

If we examine the different pollutants separately, it is clear that the highest amounts are removed from those pollutants that have the highest concentrations in the city in general (Tab. 3).

	CO	**O_3**	**NO_2**	**PM10**	**SO_2**
Removed pollutant (kg/yr)	18598	596352	72672	406469	34152

Tab. 3. Total amounts of removed pollutants.

In the investigated urban forest in Szeged, where there is no considerable industrial emmission, the highest removal values can be observed in the case of O_3 and PM10, which are mainly from traffic. In the concentrations of the latter, dust coming from the neighbouring landscapes as a result of wind erosion may also have a significant role (Szatmári, 2005).

4. Discussion

The structural characteristics of the urban forest in Szeged are mainly similar to those of other European cities.The non-native species' share reaching or even more than 50% is typical of other cities as well, where i-Tree analyses were carried out (e.g. Chaparro and Terradas, 2009; Rogers et al., 2011). The greater or smaller weight of particular species compared to their number of individuals is a consequence primarily of the size distribution, but there are some species-specific differences even with this type of categorisation, which could provide valuable information for species selection. As an example, in the urban forest of the city centre of Szeged, the worse condition of two native Tilia species (T. cordata, T. platyphyllos) was detected, which refers to their worse urban tolerance, and calls attention to the need for further research specific to these trees. The adequate general condition of Acer platanoides trees appears also in other studies. In the contribution of Pothier and Millward (2013) on an urban forest analysis in Toronto, the individuals of this species appeared to be the best from the point of view of carbon sequestration and air pollution removal (due partly to the good tree condition of the population). Thus, this species might be considered suitable for urban planting in the climatic circumstances of these studies, without regard on nativeness.

From the investigated ecosystem services, the results of carbon sequestration can be compared more easily to results of other studies, as air pollution removal is calculated based on hourly meteorological data and on pollutant concentrations, which have very strong variability between different cities. The average carbon storage of 410,8 kg/tree and yearly carbon sequestration of 14,01 kg/tree (referring to the complete urban forest in Szeged) are close to the results of Wälchli (2012) obtained for Zürich (Switzerland) with i-Tree Eco analysis (348,9 kg and 12,97 kg/yr), and to the results of Russo et al. (2014) for Bolzano (Italy), calculated with allometric equations (377,4 kg and 12,1 kg/yr). This also shows that before planting of trees of different species, it is worth investigating their general condition and service providing capacity in the city. For that, creating and maintaining a tree cadastre database and analyses of ecosystem services similar to the ones presented in this study may be advisable in as many cities as possible.

References

Bolund P., Hunhammar S., 1999. Ecosystem services in urban areas. *Ecological Economics*, **29**, 293-301.

Chaparro L., Terradas J., 2009: Ecological Services of Urban Forest in Barcelona. Barcelona City Council, Barcelona, Spain: Department of Environment. 96 p.

City of Melbourne., 2012: Urban Forest Strategy – Making a great city greener 2012-2032 [online]. website of the city of Melbourne [cit. 15.06.2015]. Available at: <http://www.melbourne.vic.gov.au/Sustainability/UrbanForest/Documents/Urban_Forest_Strategy.pdf>

Gómez-Baggethun E., Barton D.N., 2013: Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, **86**, 235-245.

Haase D., Larondelle N., Andersson E., Artmann M., Borgström S., Breuste J., Gómez-Baggethun E., Gren A., Hamstead Z., Hansen R., Kabisch N., Kremer P., Langemeyer J., Rall E.L., McPhearson T., Pauleit S., Qureshi S., Schwarz N., Voigt A., Wurster D., Elmqvist T., 2014: A Quantitative Review of Urban Ecosystem Service Assessments: Concepts, Models and Implementation. *AMBIO*, **43**, 413-433.

i-Tree., 2014: i-Tree Eco User Manual v5.0 [online]. [cit. 15.16.2015]. Available at: <http://www.itreetools.org/resources/manuals/Eco_Manual_v5.pdf >

Jim C.Y., Chen W.Y., 2008: Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). *Journal of Environmental Management*, **88**, 665–676.

Kirnbauer M.C., Baetz B.W., Kenney W.A., 2013: Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels. *Urban Forestry and Urban Greening,* **12**, 401–407.

Liu C.F., He X.Y., Chen W., Zhao G.L., Li L., Xu W.D., 2008: Ecological benefit evaluation of urban forests in Shenyang City based on QuickBird image and CITYgreen model. *Chinese Journal of Applied Ecology,* **19**, 1865–1870.

Makra L., 2005: The role of traffic in modifying air quality in a medium-sized city, Szeged, Hungary. *Epidemiology,* **16**, S62.

MEA, 2005: Millennium Ecosystem Assessment: Ecosystems and Human Well-being –Synthesis. Island Press, Washington, DC. 155 p.

Nowak D.J., Crane D.E., Stevens J.C., Hoehn R.E., Walton J.T., Bond J., 2008: A Ground-Based Method of Assessing Urban Forest Structure and Ecosystem Services. *Arboriculture and Urban Forestry,* **34**, 347-358.

Nowak D.J., Greenfield E.J., Hoehn R.E., Lapoint E., 2013: Carbon storage and sequestration by trees in urban and community areas of the United States. *Environmental Pollution*, **178**, 229-236.

O'Campo, P., Salmon C., Burke, J., 2009: Neighbourhoods and mental well-being: What are the pathways?. *Health and Place*, **15**, 56–68.

Perrings C., Duraiappah A., Larigauderie A., Mooney H., 2011: The Biodiversity and Ecosystem Services Science-Policy Interface. *Science,* **331**, 1139–1140.

Pothier A.J., Millward A.A., 2013: Valuing trees on city-centre institutional land: an opportunity forurban forest management. *Journal of Environmental Planning and Management,* **56**, 1380-1402.

Rogers K., Jarratt T., Hansford D., 2011: Torbay's Urban Forest – Assessing Urban Forest Effects and Values [online]. Torbay Council website [cit. 15.06.2015.]. Available at: <http://www.torbay.gov.uk/tuf.pdf>

Russo A., Escobedo F.J., Timilsina N., Schmitt A.O., Varela S., Zerbe S., 2014: Assessing urban tree carbon storage and sequestration in Bolzano, Italy. International Journal of Biodiversity Science, Ecosystem Services and Management, **10**, 54–70.

Szatmári J., 2005: Szélerózió-veszélyeztetettség értékelése a Duna-Tisza-közén RWEQ modell alkalmazásával (Evaluation of Wind Erosion Risk on the Danube-Tisza Interfluve using the Revised Wind Erosion Equation (RWEQ). Paper presented at the II. Hungarian Geographical Conference, Szeged, 2-4.09.2004. [online]. [cit.15.06.2015]. Available at: < http://geography.hu/mfk2004/mfk2004/cikkek/szatmari_jozsef.pdf>

TEEB., 2010a: The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB. Earthscan, London-Washington. 39 pp.

TEEB., 2010b: The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: Ecological and Economic Foundations. ed. by P. Kumar, Earthscan, London-Washington. 410 p.

Tyrväinen L., Silvennoinen H., Kolehmainen O., 2003: Ecological and aesthetic values in urban forest management. *Urban Forestry and Urban Greening,* **1**, 135–149.

Unger J., Lelovics E., Gál T., 2014: Local Climate Zone mapping using GIS methods in Szeged. *Hungarian Geographical Bulletin,* **63**, 29–41.

Wälchli G., 2012. Ökosystemdienstleistungen als ökonomische Strategie? i-Tree: ein Instrument für die Wertermittlung von Stadtbäumen Zusammenfassung [dissertation]. Wädenswil: Zürcher Hochschule für Angewandte Wissenschaften. 123 p.